

Crack Growth Behavior in the Threshold Region for High Cyclic Loading

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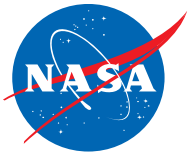
NASA JSC, Houston, TX 77058

and

J. Ventura, J. Martinez and F. Samonski

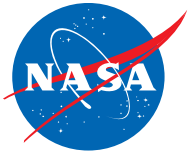
Jacobs ESC Group, Houston, TX 77058

Fatigue Crack Threshold Investigations at JSC



- CY 2006 – 2010: Two concurrent FAA sponsored projects
 1. Development of analysis tools to **assess the damage tolerance of rotorcraft** .
 2. Improve **damage tolerance analysis of propeller systems**,
 - (a) for crack initiation from sharp surface flaws
 - (b) for crack initiation and growth from corrosion pits.
- CY 2011: In-house project - Improved characterization of fatigue crack growth thresholds

Present Concern Regarding Threshold Behavior

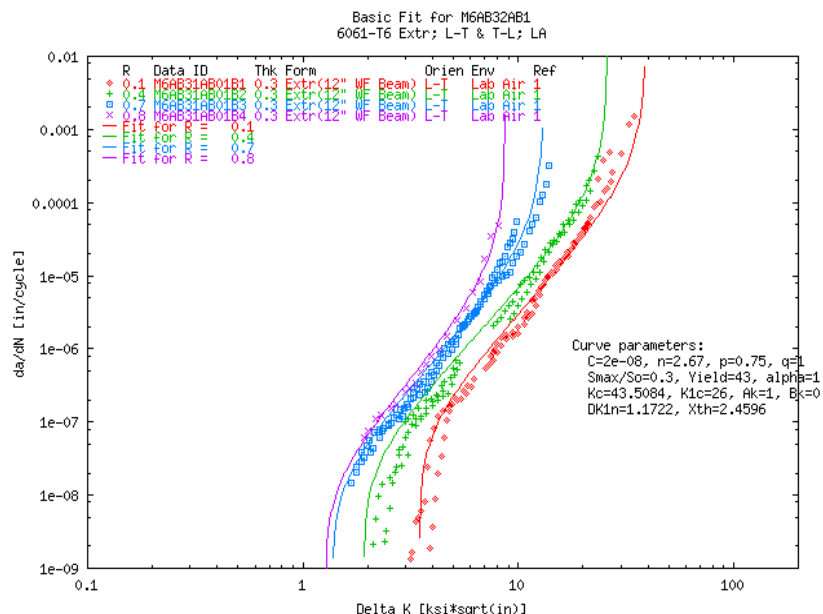


- What is the cause of “fanning” of da/dN data in the threshold region for some materials?
 - (1) Is fanning caused by the ASTM load shedding test method (as some believe), and the resulting data is not valid for use in damage tolerance analysis ?
 - (2) Or is sometimes the cause of fanning a result of inherent characteristics of the material and the data is valid and acceptable for use in damage tolerance analysis?

EXAMPLE OF THE THRESHOLD FITTING PROBLEM

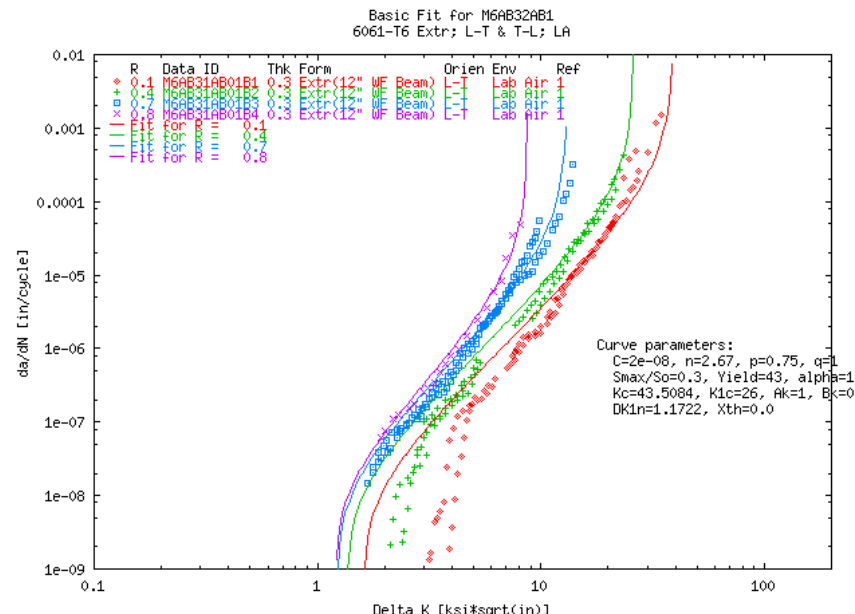
NASGRO FITS: 6061-T6 AL Extr, L-T & T-L, LA

With Fanning Fit



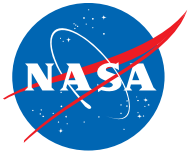
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Without Fanning Fit



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Known Test Conditions That Cause Fanning



- (1) Crack tunneling – i.e., specimen thickness
- (2) Moist environment - i.e., fretting corrosion

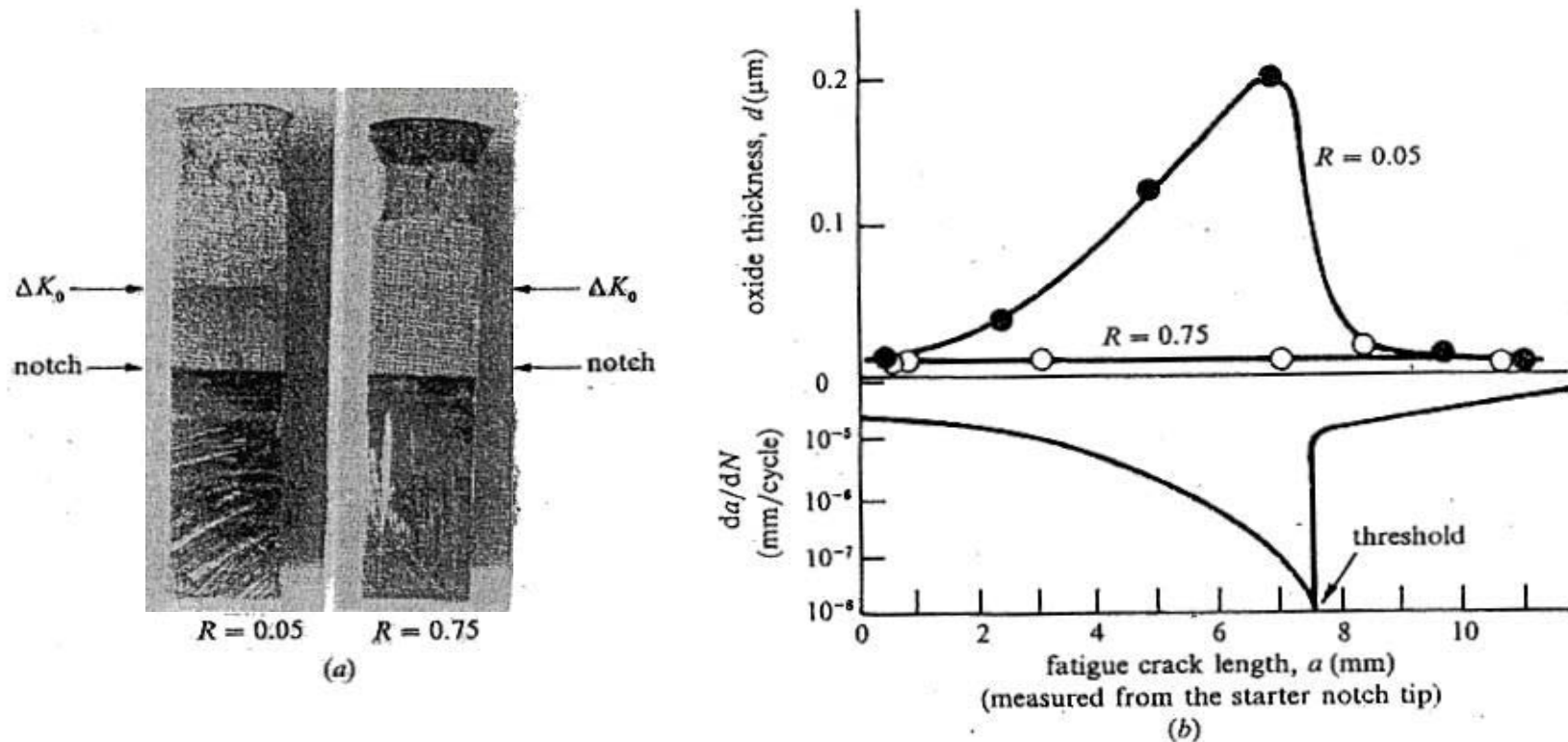
Crack Tunneling Example

- For 0.5" thick specimens, crack front tunneling occurred just before final threshold and caused elevated threshold values.



- Thus, all remaining specimens were re-machined to a thickness of 0.2", and the tunneling was eliminated.

Oxide Buildup at Threshold Crack Tip (Fretting Oxidation)

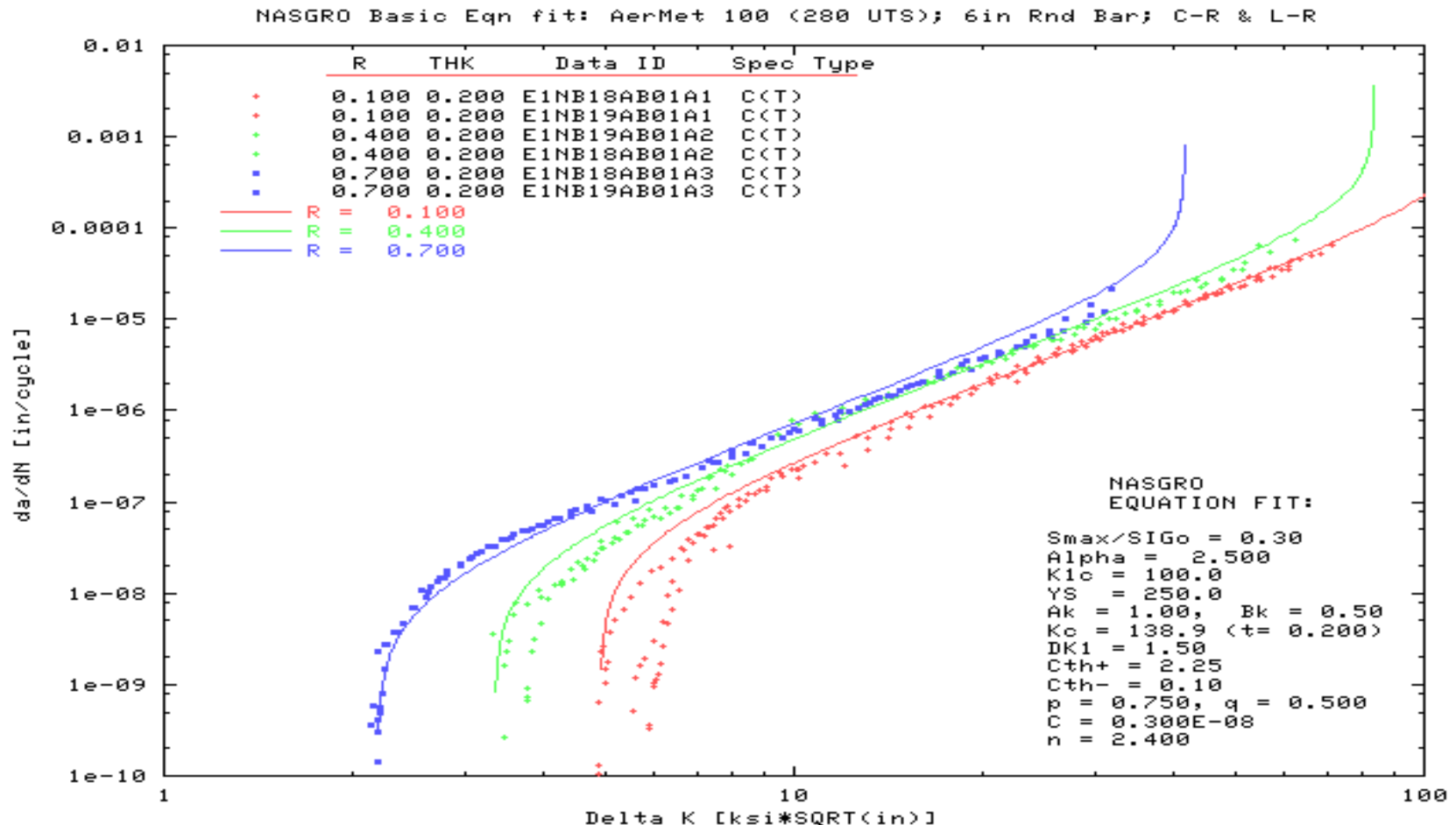


(a) Macroscopic appearance of oxide deposits on near-threshold fatigue fracture surfaces in a $2\frac{1}{4}\text{Cr}-1\text{Mo}$ bainitic steel fatigue tested in moist air at $R = 0.05$ and 0.75 . (b) Corresponding Auger measurements of oxide layer thickness as a function of crack length and crack growth rates. (From Suresh, Zamiski & Ritchie, 1981)

Example of Significant Fanning that Occurred in Lab Air Testing

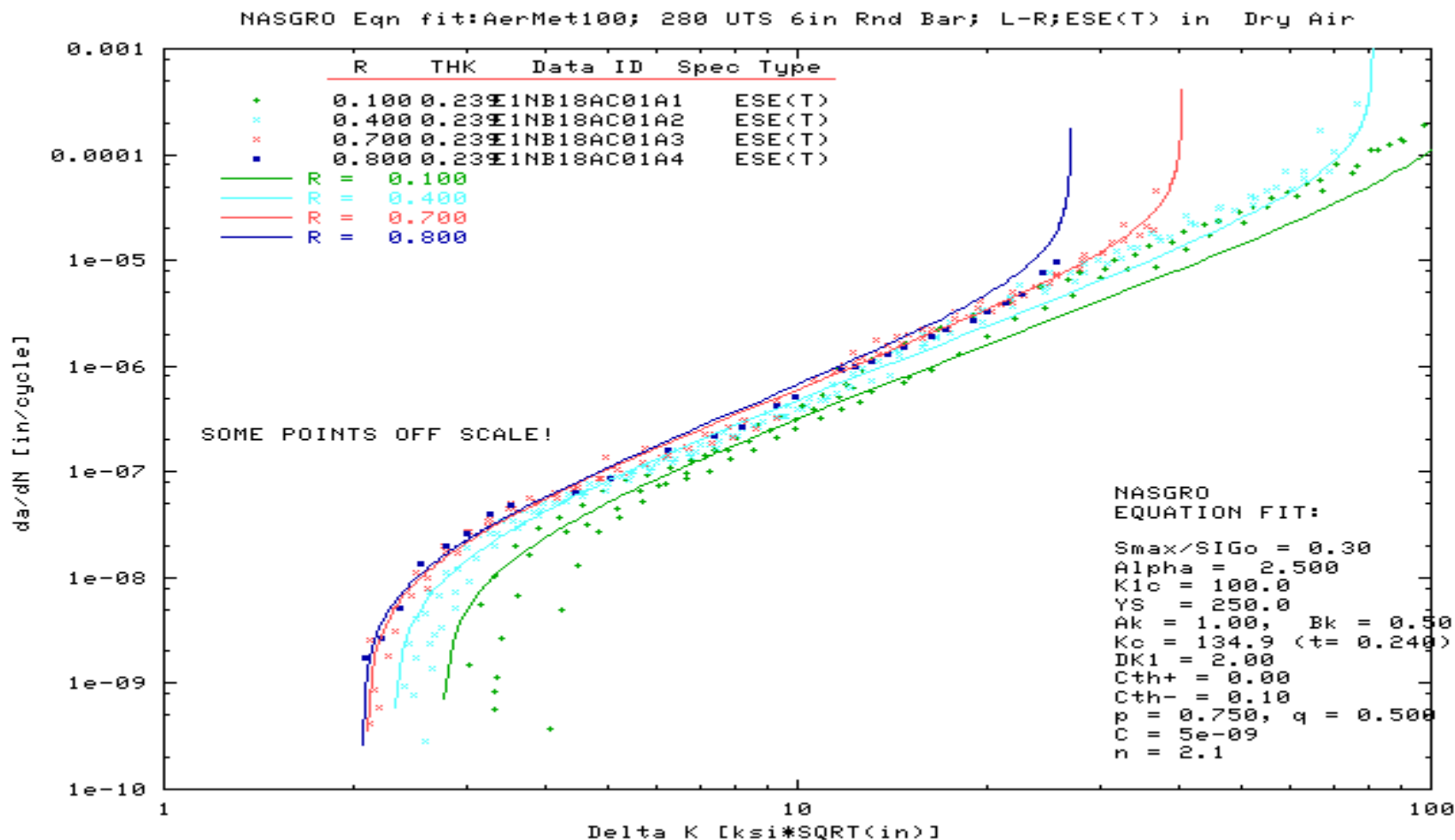


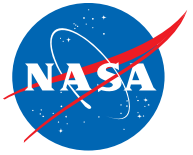
AerMet 100 Lab Air Data Fit – Cth = 2.25



Example of Decreased Fanning in Dry Air Testing

AerMet 100 Dry Air Data Fit – Cth = 0



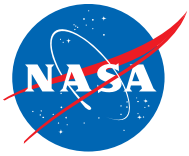


Other Causes of Fanning

Causes that result from inherent material characteristics which affect crack surface morphology in the threshold region:

- When ratio of **crack tip yield zone size/grain size** is < 1 and crack surface changes from striated to a faceted morphology in threshold region.
- When the material **dislocation property** results in multiple crack bifurcations and branching in threshold da/dN region ($< 1E-8$ inches/cycle).

Example of Faceted (Cleavage Like) Fatigue Crack Growth in Threshold da/dN Regime



Hertzberg 1976: Micromorphology in the Ultra-Low Growth Rate Regime

2024-T3 Aluminum

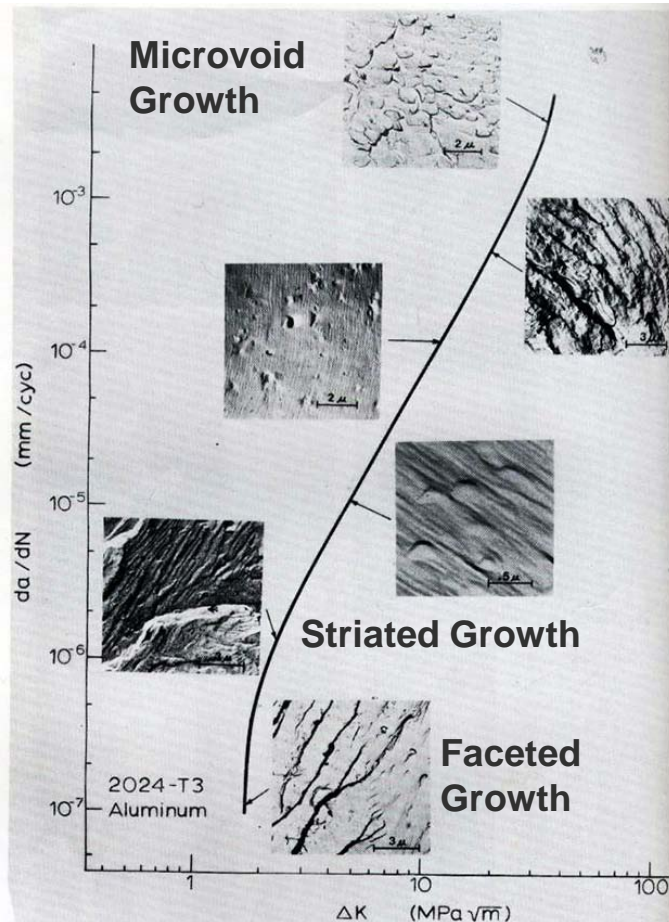
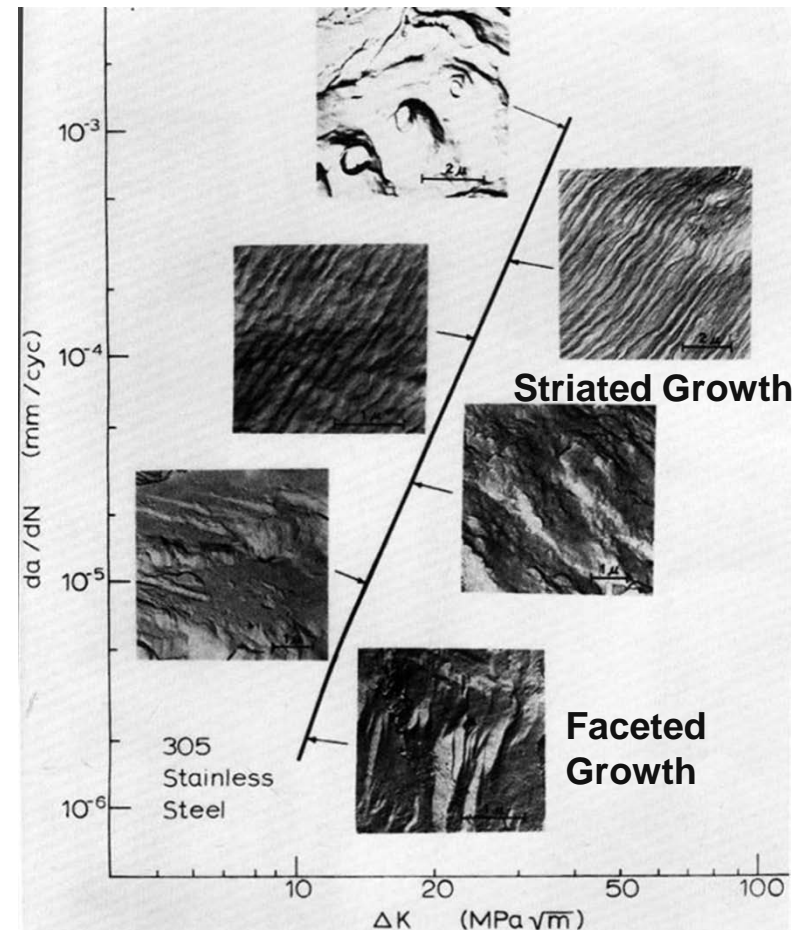
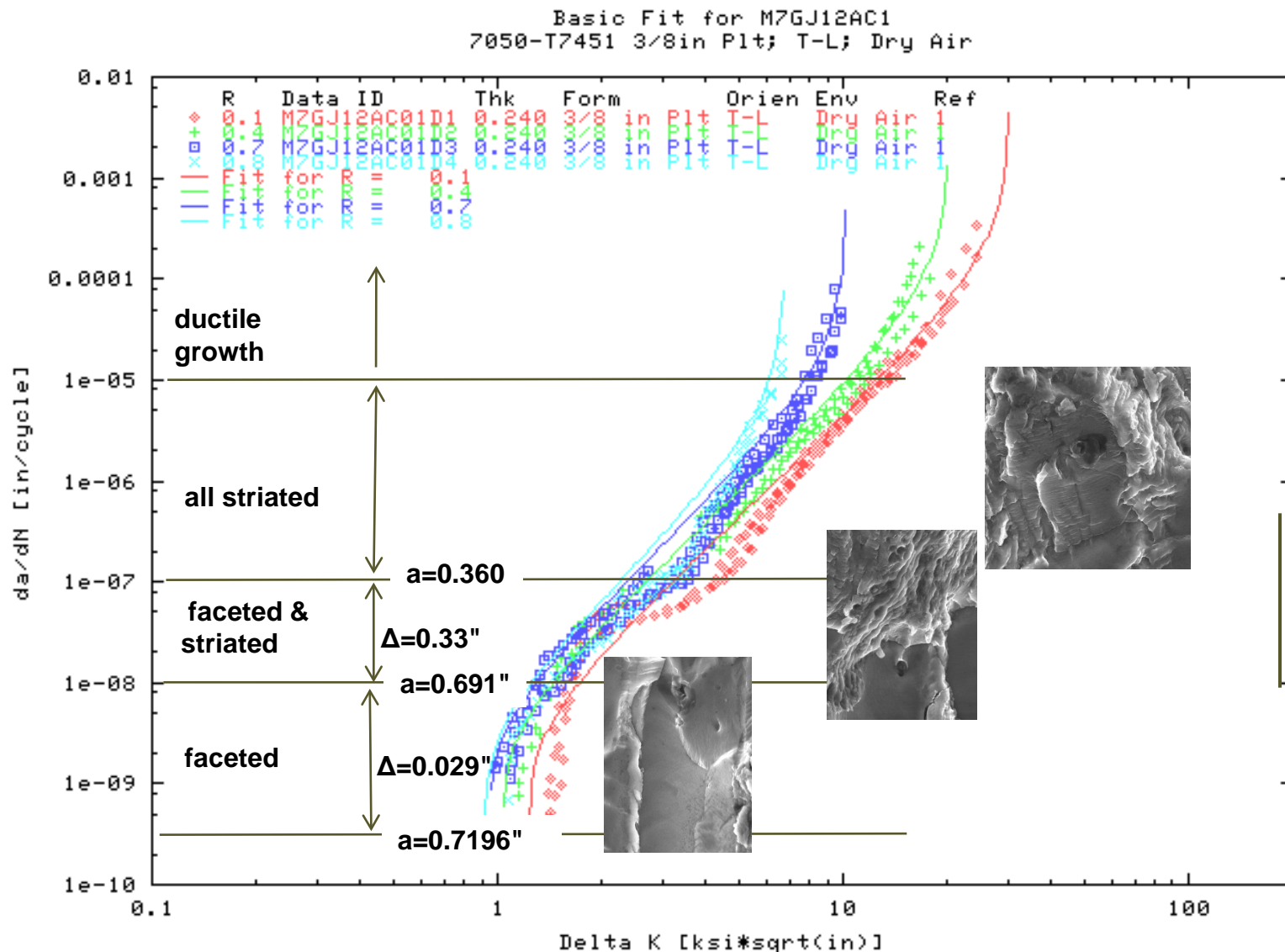


FIG. 2—Electron fractographs showing fatigue fracture surface micromorphology at various points on the da/dN versus ΔK plot for 2024-T3 aluminum alloy.

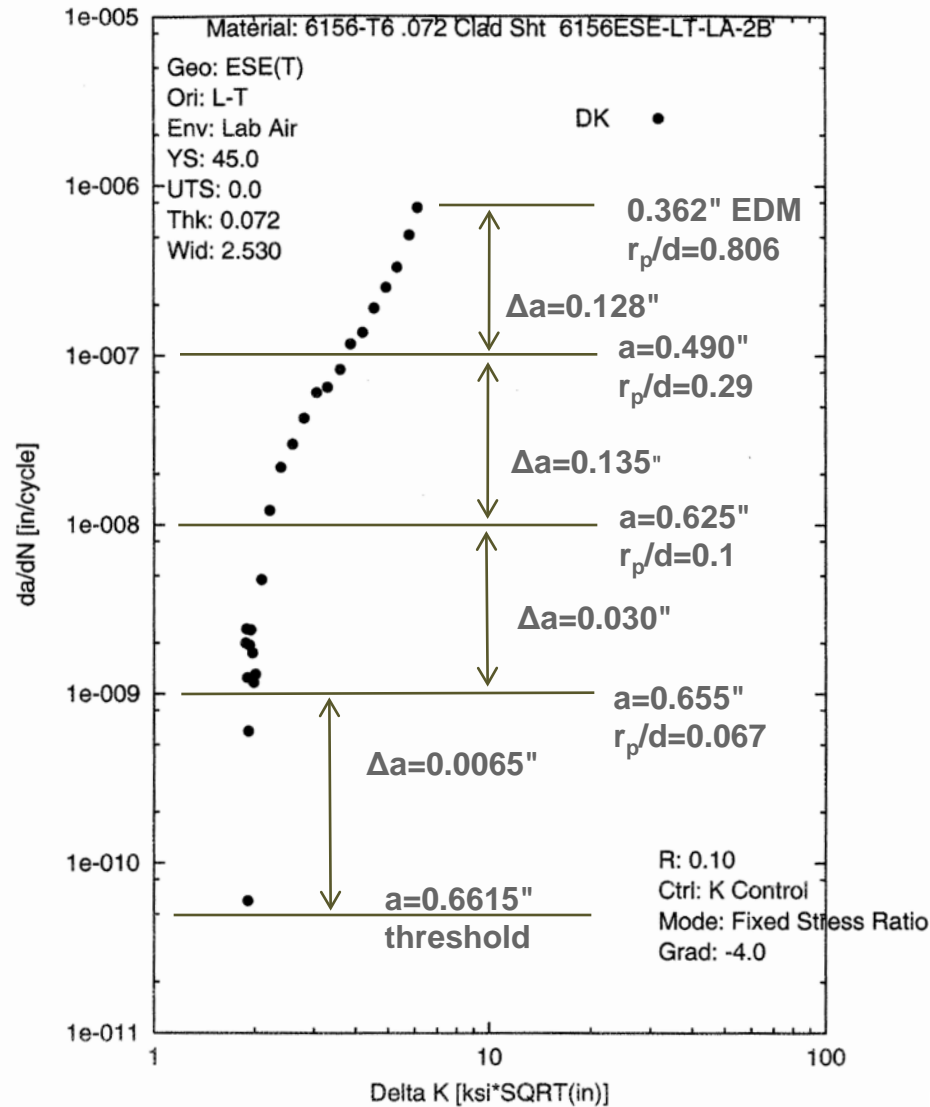
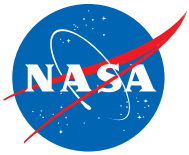
305 Stainless Steel



Variation In Crack Surface Morphology for 7050-T7451 Tests



Load Shedding Test of 6156-T6 ESE(T) Specimen

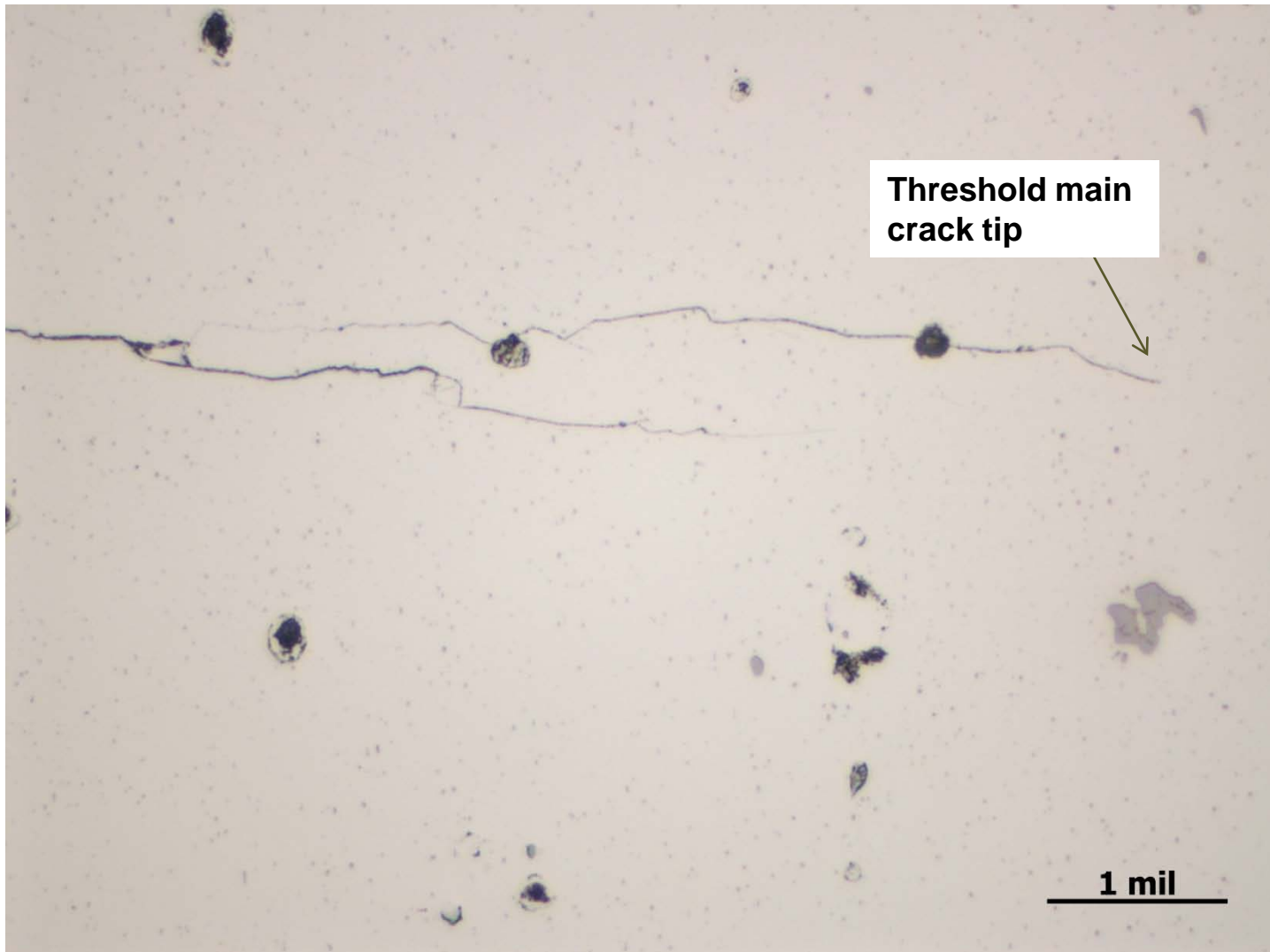
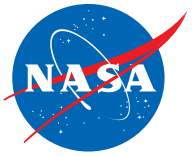


For plane strain:

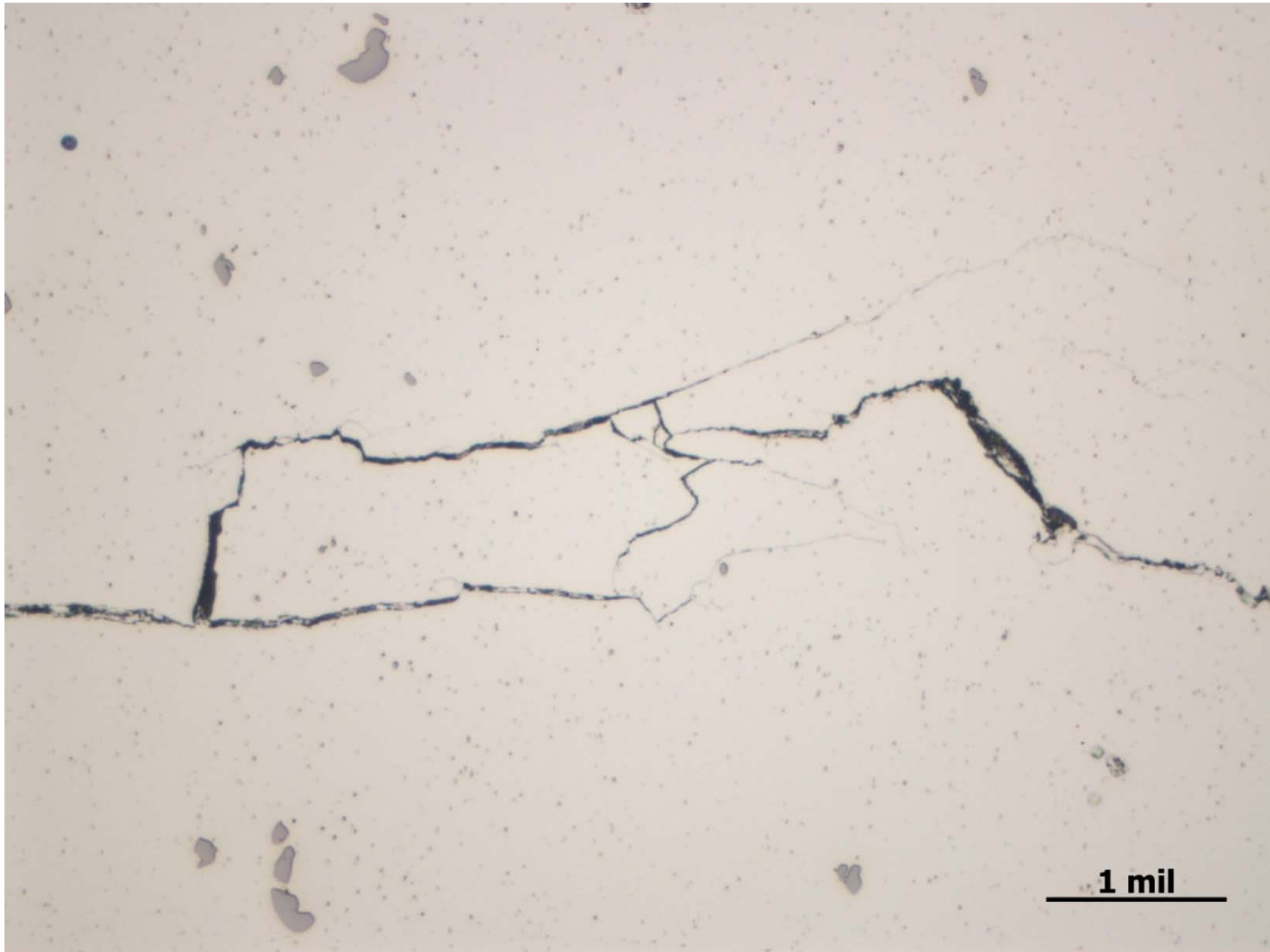
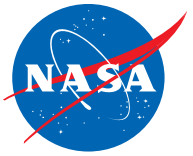
$$r_p = \frac{1}{6\pi} \left(\frac{K_{\max}}{YS} \right)^2$$

Grain diameter,
 $d = 1.5 \times 10^{-3}$

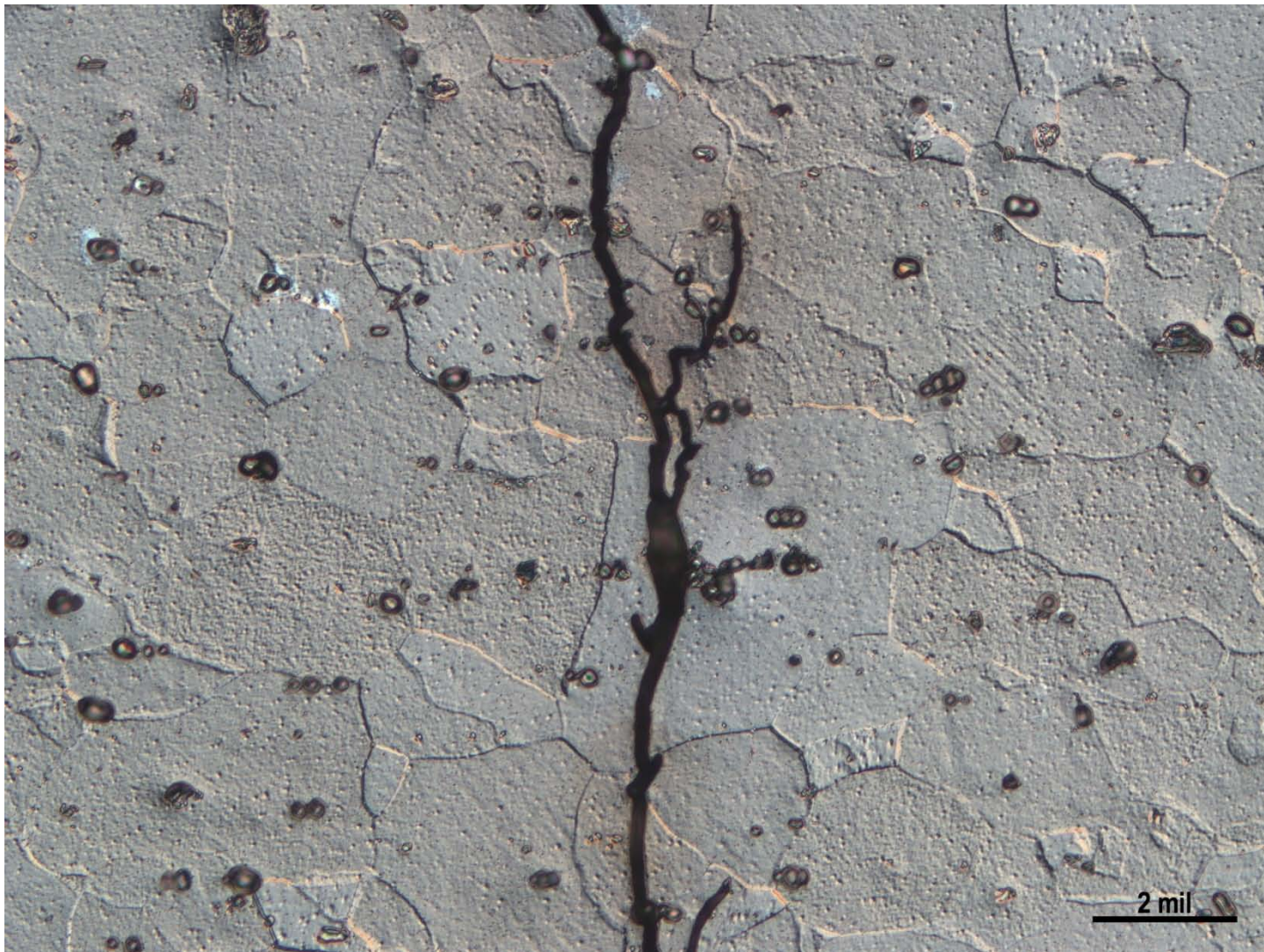
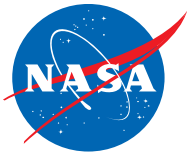
AI 6156-T6, R=0.1: Threshold Main Crack Tip



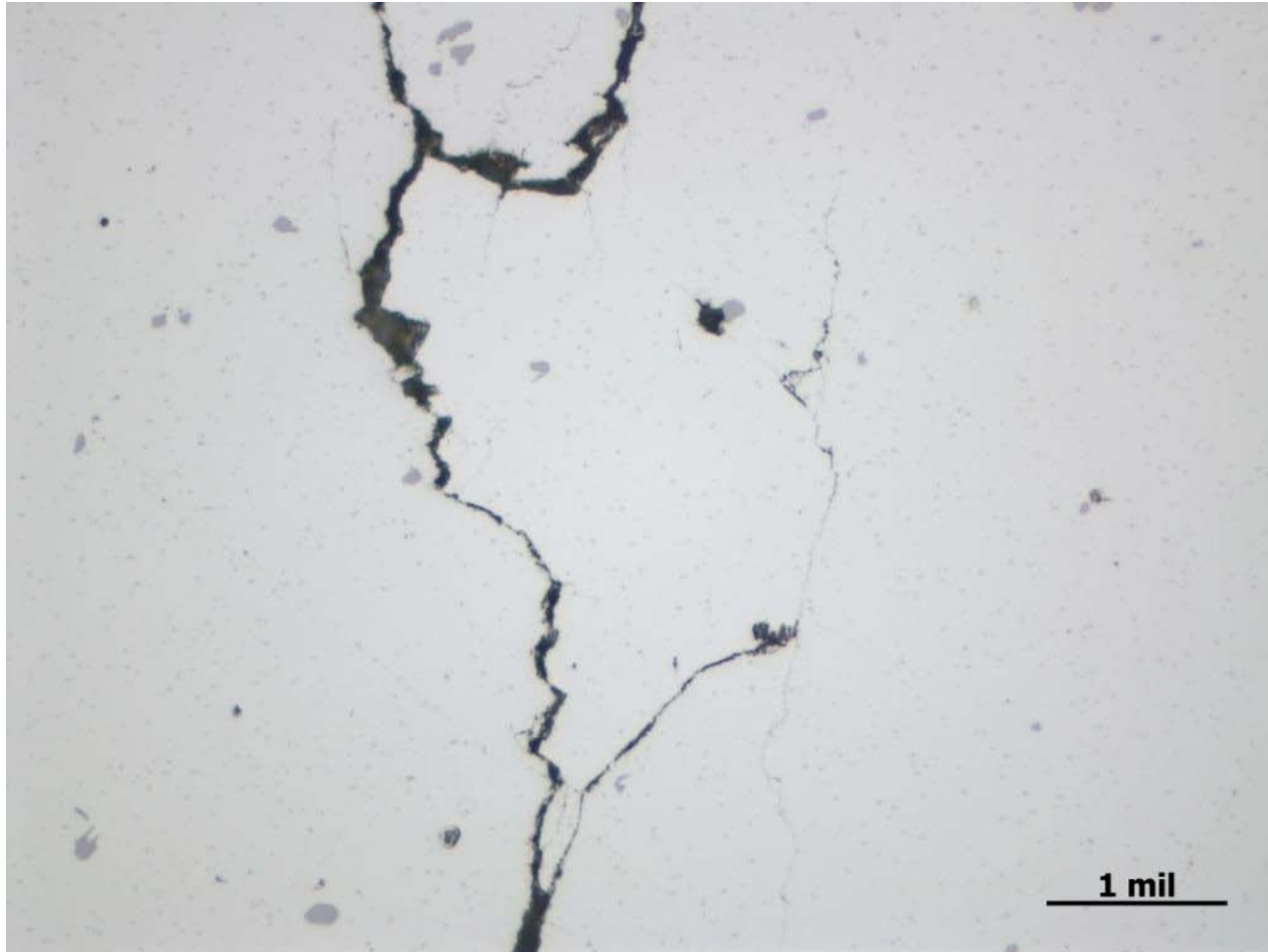
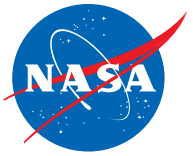
Al 6156-T6, R = 0.1: Close to Threshold Tip



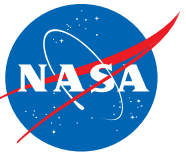
AI 6156-T6: Load Shedding Crack (etched to show grains)



Al 6156-T6 Specimen, R = 0.7: Midway to Threshold Tip



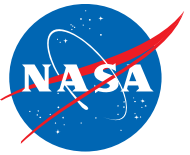
AI 2524-T3 Specimen Showing a Crack Closure Point



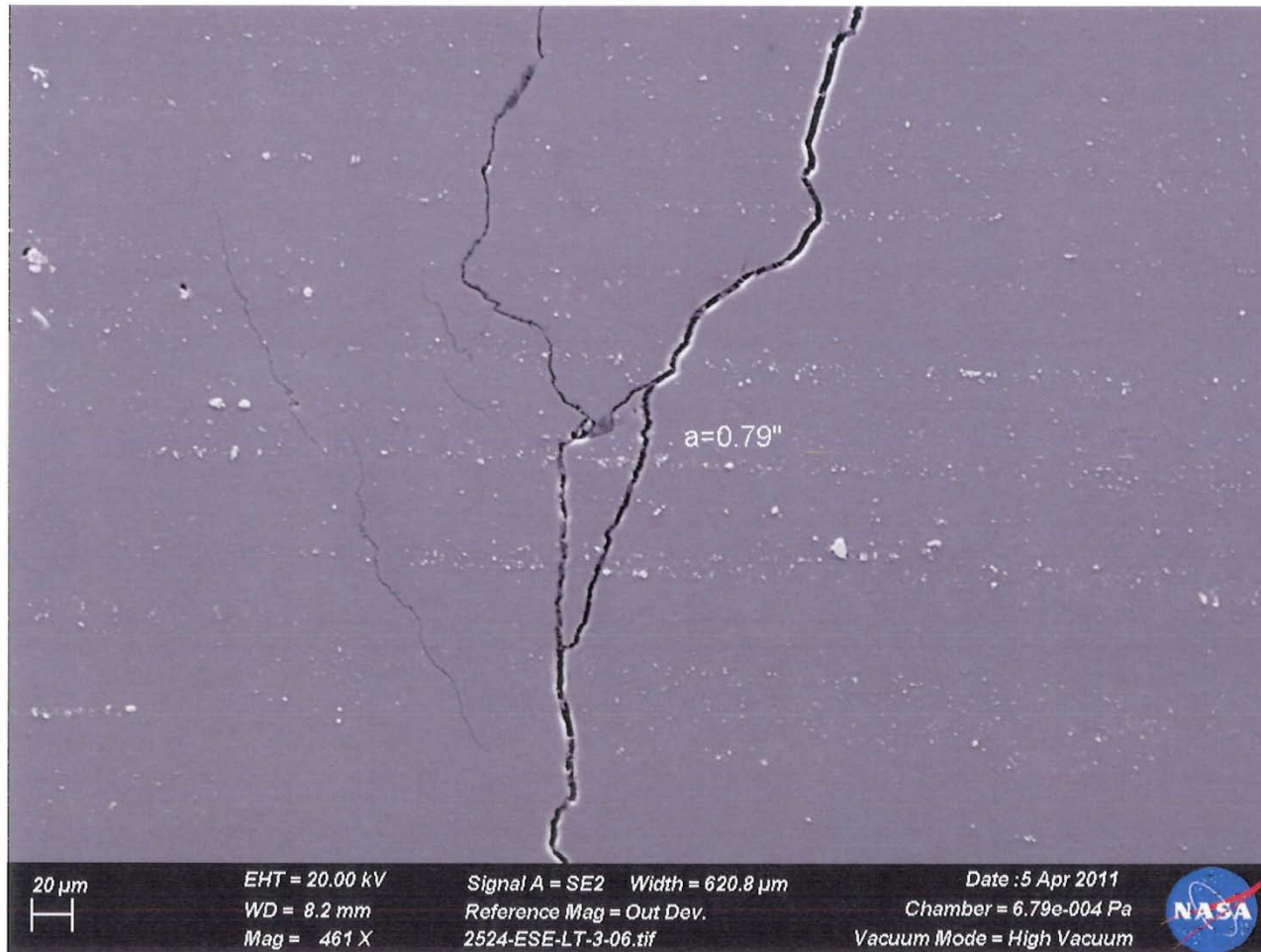
Fatigue Crack Sample: 2524 ESE-LT-3



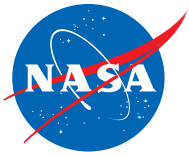
Al 2524-T3 Specimen: Midway in Load Shedding Phase



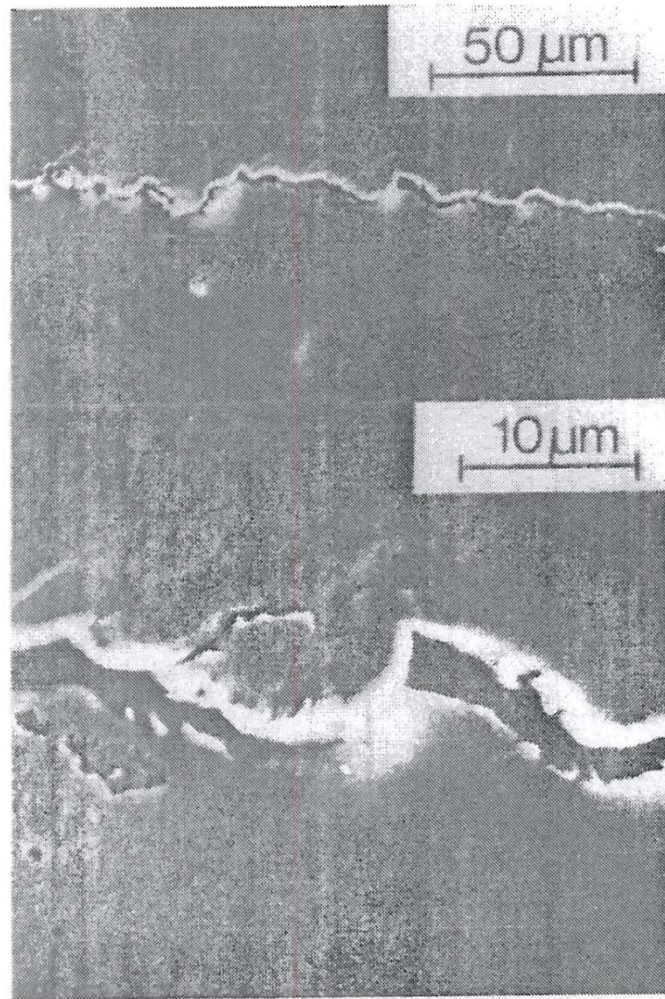
Fatigue Crack Sample: 2524 ESE-LT-3

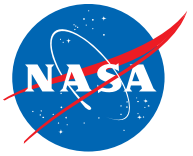


IMI 685 Ti Specimen Showing a Crack Closure Point



MA Hicks, Fatigue of Engineering Materials, & Structures
Vol. 6, No. 1, pg 59





Summary

- The present studies show that fanning in the threshold regime is likely caused by other factors than a plastic wake developed during load shedding.
- The cause of fanning at low R-values is a result of localized roughness, mainly formation of a faceted crack surface morphology , plus crack bifurcations which alters the crack closure at low R-values.
- The crack growth behavior in the threshold regime involves both **crack closure theory** and **the dislocation theory of metals**.
- Research will continue in studying numerous other metal alloys and performing more extensive analysis, such as the variation in **dislocation properties (e.g., stacking fault energy)** and its effects in different materials.